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Structure Dependence of over 10 GHz Lateral Si-PIN Photodiode Fabricated by COMS Compatible Process

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Abstract

Lateral PIN type thin film Si photodiodes were fabricated on silicon-on-insulator substrate by a CMOS compatible process. Its characteristic was measured in 0.8 μm wavelength region. The intrinsic region width (L_i) and the electrode spacing (L_s) of the frequency were demonstrated. The largest -3 dB bandwidth of 11.1 GHz was obtained at $L_i = L_s = 1.10$ μm at the reverse bias voltage of 10 V.

1. Introduction

The data transmission speed in an electronic system can be enhanced by utilizing an optical transmission technique. An optical interconnect technology has been studied thoroughly and silicon photonics have gained a lot of popularity in recent years [1],[2]. Silicon is generally used as a waveguide material in 1.3-1.55 μm wavelength region, while light sources and photodiodes are fabricated by Ge-on-Si or III-V-on-Si technology. On the other hands, it is an attractive approach to use silicon as a photodiode material in 0.8 μm wavelength region. High quality silicon film is suitable for electrical and optical performances of the devices, and a low dark current and a high speed Si photodiodes are reported [3],[4]. Si photodiode has high compatibility with complimentary meta-oxide-semiconductor (CMOS) processing techniques, and can be fabricated at low cost compared with the other materials. For 0.8 μm wavelength range optical interconnect, AlGaAs/GaAs vertical cavity surface emitting lasers (VCSEL) can be used as an off-chip light source, and it is less expensive than lasers operating in 1.3-1.55 μm wavelength region. Combining the Si photodiodes and the AlGaAs/GaAs VCSEL, low cost optical interconnect can be realized.

As waveguide materials for 0.8 μm wavelength range optical interconnect, amorphous silicon (a-Si), silicon nitride (Si_3N_4), and SiON are usable. In our research, we use Si_3N_4 as a waveguide material. Si_3N_4 film can be deposited on a Si thin film. Si_3N_4 has bandgap of 5.1 eV, and transparent in 0.8 μm wavelength region. High refractive index of Si_3N_4 (n~2) allows a compact optical integrated circuit. Waveguides formed using Si_3N_4 tend to exhibit a low propagation loss in the visible regime [5],[6]. It is possible to integrate a Si_3N_4 waveguide on a Si photodiode with a evanescent light coupling. Si photodiode integrated with Si_3N_4 waveguide has many merits: low dark current of high quality Si layer, high responsivity of waveguide coupling, fast response of thinned absorption layer, and low input capacitance of low dielectric constant of Si.

In this paper, lateral PIN type Si photodiodes were fabricated on silicon-on-insulator (SOI) substrate by a CMOS compatible process. To demonstrate fundamental characteristics of the photodiodes, we characterize the device performances by illuminating the light on top of the devices, instead of a waveguide evanescently coupling.

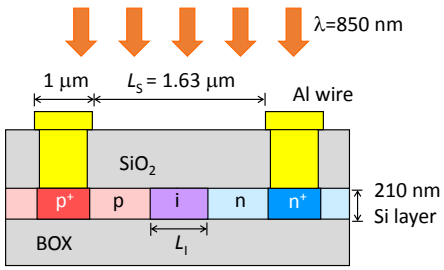

Fig. 1 Schematic cross-sectional view of Si-PIN photodiodes fabricated on SOI with a 210 nm thick Si absorption layer.

2. Device structure

SOI Si-PIN photodiodes were fabricated through a foundry service and a shuttle process of the institute of microelectronics (IME). Figure 1 shows a basic schematic cross-sectional view of thin film Si-PIN photodiodes fabricated on SOI substrate, with a 210 nm thick Si absorption layer. A basic structure of lateral PIN type Si photodiode was designed with intrinsic region width (L_i) of 1μm, aluminum electrode with width of 1 μm and spacing (L_s) of 1.63 μm. A top view of the fabricated SOI Si-PIN photodiode is shown in Fig. 2. The optical receiving area and pad electrode size are 20 × 20 μm^2 and 60 × 60 μm^2, respectively. The Si layer in the outside of the receiving area is etched completely to avoid the optical absorption. In the devices, a fast response is estimated due to the thin absorption layer.

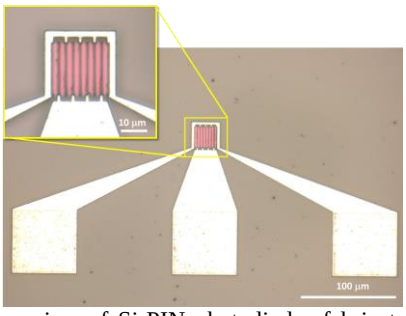

Fig. 2 Top view of Si-PIN photodiodes fabricated by the institute of microelectronics (IME).

In order to investigate the frequency response dependence on intrinsic width (L_i) and electrode spacing (L_s). Variable intrinsic width and electrode spacing were designed as shown in Table 1.

Table 1 Parameter of intrinsic region width and electrode spacing

Intrinsic region width	L_i	0, 1/3 L_s, 2/3 L_s, L_s
Electrode spacing	L_s	0.75 μm, 1.10 μm, 1.63 μm, 2.50 μm, 4.25 μm

3. Measuremental results

SOI Si-PIN photodiodes were measured in 0.8 μm wavelength region. A laser light with the wavelength of 850 nm is intensity modulated by an electro-optic modulator with a bandwidth more than 25 GHz, and the frequency response of the modulator and RF cables is compensated by using a commercial GaAs PIN photodiode with a bandwidth of 30 GHz.

Figure 3 shows an intrinsic region width dependence of the frequency response at the electrode spacing of 1.63 μm. According to the table 1, the samples with intrinsic region width of 0, 0.54, 1.09, and 1.63 μm were measured at the reverse bias voltage of 10 V. With increase of ratio of L_i/ L_s from 0 to 2/3, the -3dB bandwidth increased gradully, but no significant change between 2/3 and a full depletion type PIN photodiode. The largest -3dB bandwidth of 11.0 GHz was obtained at $L_i = L_s = 1.63$ μm.

In order to confirm the electrode spacing depencdence of the bandwidth with the full depletion type PIN photodiodes, the samples with electrode spacing of 0.75, 1.10, 1.63, 2.50, and 4.25 μm were measured at the bias voltage of 10 V. Figure 4 shows the frequency response curves of electrode spacing of 0.75, 1.10, and 2.50 μm, and table 2 shows the -3dB bandwidths of all samples. With the miniaturization of electrode spacing, a higher fraquency response can be supplied because of a shorter drift time. On the other hand, a faster fraquency response will be limited by the increase of capacitance at the same receiving size. It was confirmed that the largest -3dB bandwidth of 11.1 GHz was obtained at $L_i = L_s = 1.10$ μm.

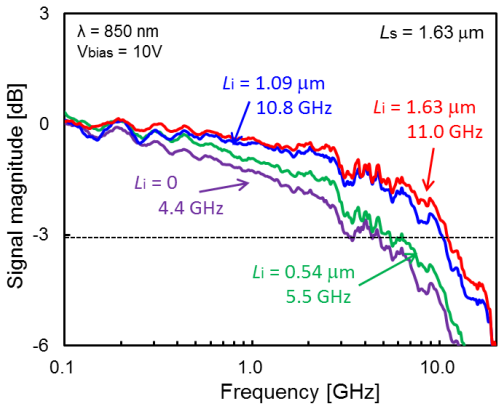

Fig. 3 Intrinsic region width dependence of frequency response with electrode spacing of 1.63 μm at 10 V at 850 nm.

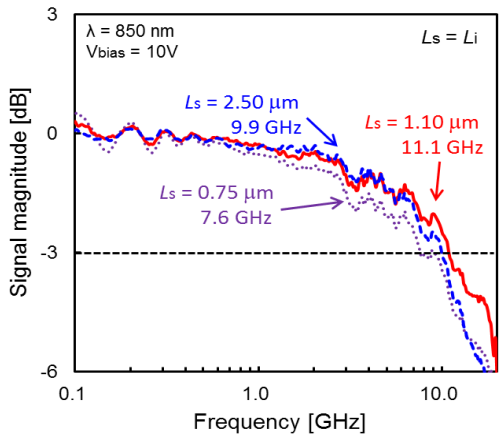

Fig. 4 Electrode spacing dependence of the frequency response with full depletion type PIN photodiodes at 10 V at 850 nm

Table 2 -3 dB bandwidths of variable electrode spacing with full depletion PIN photodiodes

Electrode spacing (μm)	0.75	1.10	1.63	2.50	4.25
-3 dB bandwidth (GHz)	7.6	11.1	11.0	9.9	0.65

4. Conclusions

We fabricated lateral PIN type thin film Si photodiodes on SOI substrate by a CMOS compatible process. The frequency response dependence of intrinsic width (L_i) and electrode spacing (L_s) were demonstrated. The largest -3 dB bandwidth of 11.1 GHz was obtained at the case of $L_i = L_s = 1.10$ μm at the reverse bias voltage of 10 V in 0.8 μm wavelength region. This devices can be operated under 10 V leading to low power consumption. A wider bandwidth can be obtained by optimizing a electrode pad size. The devices can be expected to realize the optical integrated circuits integrated with Si LSIs.

Acknowledgements

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